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Monostatic observation of the *F* region structure

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F region parameters can change by relatively large amounts over short periods of time (fraction of an hour) under so-called "undisturbed" conditions. There is evidence that these changes are due to propagating acoustic gravity waves. While the periods of these variations and other local parameters (Doppler velocity and angle of arrival) can be measured with a high-resolution digital ionosonde, other quantities like wavelength or magnitude and direction of the propagation velocity cannot be observed. The Clarke Lake radio astronomical antenna array which can be operated in the HF band allows tracking the motion of medium scale (100–500 km) disturbances by observation of the changes in the apparent position of radio stars. Some first data samples were recorded and analyzed (R. L. Higgins and B. McManus, private communication, 1987).

BACKGROUND

The scaling of ionograms at a rate of one per hour has been the standard procedure since systematic observations of the ionosphere began. The diurnal variation of the monthly median values of ionospheric parameters (except for those relating to sporadic *E* layers) seemed to indicate that this sampling rate was sufficient. The amount of time required for producing and processing these data was also often close to the upper limit affordable for most observatories before digital ionosondes and computer processing of the recordings became available. This practice led to the generally accepted picture of the ionosphere as a slowly varying medium which is mainly controlled by the solar zenith angle and is horizontally stratified, except during sunrise, sunset, and occasional solar or magnetic disturbances. This picture is also prevalent in ionospheric computer models.

Advanced digital ionosondes are capable of sampling the ionosphere and processing the resulting ionograms at a high rate of the order of one or two ionograms per minute. They also are capable of recording quantities besides virtual heights, like angle of arrival and Doppler frequency and their changes with frequency. Recordings with high temporal resolution show that the *F* region is continuously varying and that frequently relatively large changes occur over periods of a fraction of an hour. An example of this rapid variation is shown in Figure 1. This figure shows the maximum usable frequency over a 3000-km path, the MUF(3000), as derived from a sequence of ionograms recorded at 6-min intervals. The hourly values are marked with large crosses. It is obvious that hourly values definitely *undersample the true* behavior of the *F* region. The hourly values at 0900 and 1000 seem to indicate a small increase from 34 MHz to 34.5 MHz, while in reality eight of the nine values in between are less than 34 MHz and two are even less than 30 MHz. The opposite trend appears between 1100 and 1200, where the apparent hourly increase is from 36 MHz to 39 MHz, while six of the nine values recorded between the full hours are larger than 40 MHz. With hourly sampling the noon value of 39 MHz appears to be the highest of the day, while the true maximum of the day observed using 6-min sampling intervals is 5 MHz higher.

In Figure 2, two ionograms of this sequence are compared. Over the 12 min between the upper and lower ionogram, the virtual heights at 10 MHz increased by 51 km for the ordinary component and by 25 km for the extraordinary component. The corresponding increases at 12 MHz were 77 km and 68 km, respectively. Perhaps even more important is the large change of the critical frequency of approximately 1 MHz which is clearly visible in the extraordinary mode. The split traces close to the critical frequencies of both modes in the lower ionogram represent reflections from two different locations in the *F* region and give some indication of the spatial structure.

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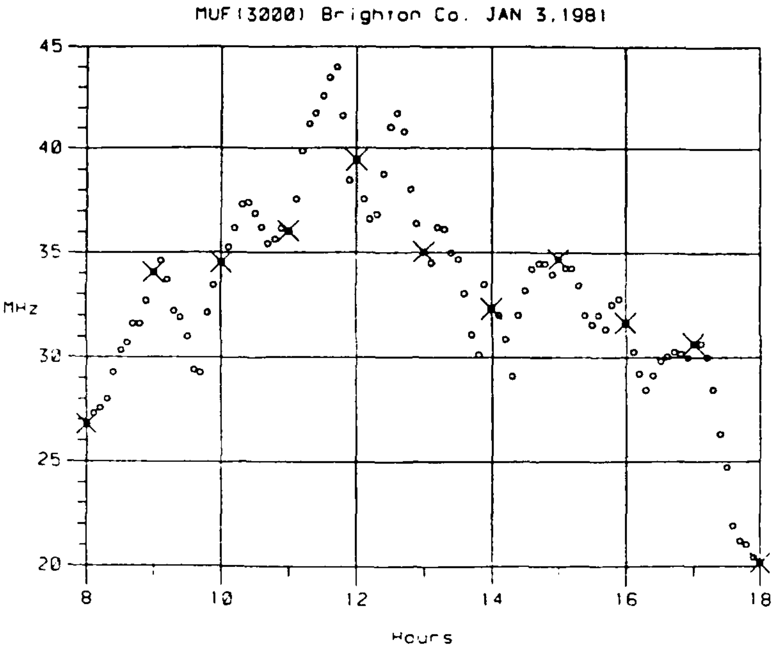

Fig. 1. Variation of MUF(3000). Ionograms were taken in 6-min intervals.

PLANS FOR CLARKE LAKE OBSERVATIONS

The Clarke Lake radio telescope is designed to operate in the frequency range 15–125 MHz [*Erickson et al.*, 1982]. It consists of a T-shaped array of antennas, one arm 1800 m long, the other arm 3000 m long. The resolution at 20 MHz is 17′ of arc. This permits very accurate measurement of the difference between apparent and true position of a radio star as a function of time. Since the direction of the antenna beam can be changed rapidly (~1 ms), several radio sources in the sky can be observed quasi-simultaneously. The differences between true and apparent positions are due to the refractive effects of the ionosphere, and temporal changes of those differences are due to changes of the electron density in the ionosphere. Traveling local modifications (for example, gravity waves) will show their effects at different times for radio stars in different positions. The time lags in question will depend on the magnitude and the direction of the propagation velocity, while time lags between the appearance of similar events can give an estimate of the spatial scale (for example, wavelength) of those modifications after the velocity has been determined.

For planning purposes some model ray-tracing studies were performed. As an example, Figure 3 illustrates in two dimensions (height and horizontal distance) a local reduction (disturbance) of the electron density in a model parabolic layer. The dashed lines are lines of constant plasma frequency, with each line's value in megahertz given to its right. The almost vertical solid lines represent 15-MHz radio rays being bent slightly as they travel through the layer. On entering the top of the figure, all rays are parallel and equidistant. At the bottom of the figure they show different directions and varying distances depending on their proximity to the disturbance. We notice that the ray passing through the center of the disturbance shows very little change in its direction. On the basis of such ray calculations, the variation of the angular difference between true and apparent position of a radio star as the model disturbance moves through the observation field is shown in Figure 4. Two curves are shown, one derived from observations of a star with a zenith angle of 40° (indicated by the numeral 4), the other for a star observed overhead (indicated by the numeral 0). Two extrema are reached in each case approximately symmetric to the time when the radio source is observed through the center of the disturbance. Other calculations not illustrated here show, as expected, that the mag-

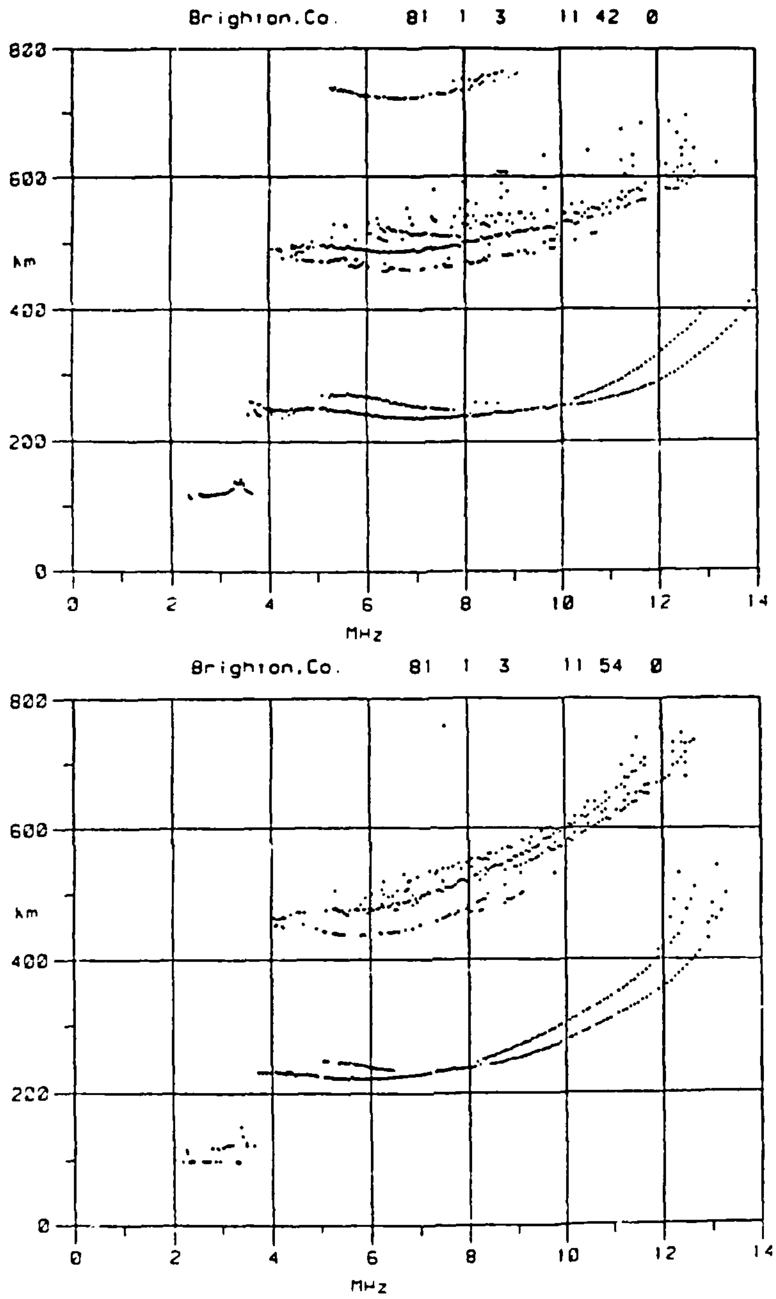

Fig. 2. Rapid changes of the virtual heights near the critical frequencies over a period of 12 min.

nitude of the angular deviation is inversely related to the radio frequency. The time between the extrema depends on the velocity of the moving disturbance and its horizontal dimension in the direction of the motion.

CONCLUSIONS

It is important to coordinate the operation of the Clarke Lake array with observations of an advanced digital ionosonde, since the data obtained with the two systems can complement each other. The array

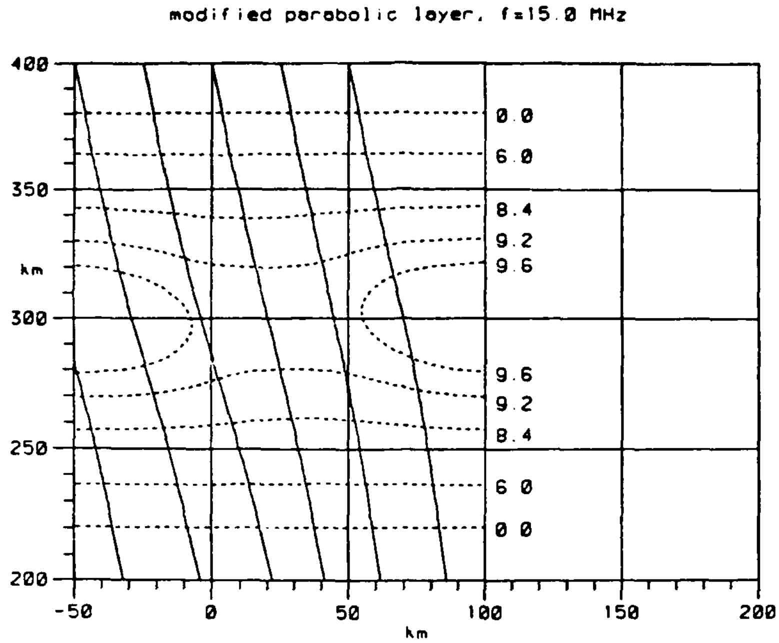

Fig. 3. Ray paths in a vertical plane through a weakly disturbed model *F* layer.

data represent a weighted integral of changes in the ray direction caused by changes of the electron density over the whole path between the radio source and the antenna array. The closer the observation frequency is to the *F* region penetration frequency, the more the array data are influenced by the *F* region peak. For optimal selection of the observation frequency a real-time knowledge of the penetration frequency is necessary.

The ionosonde data are also path integrals of ionospheric properties. However, these integrals are along a different path from the ground to the iono-

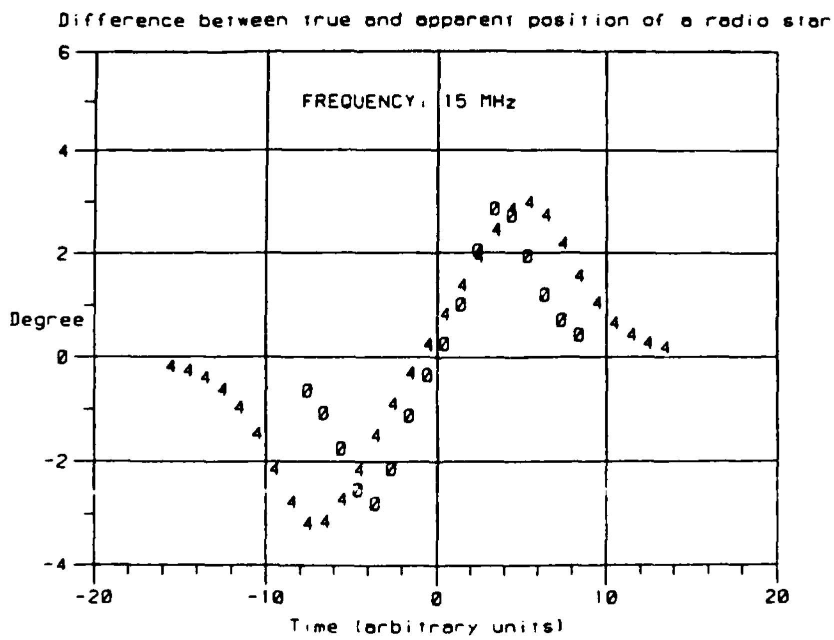

Fig. 4. Angular difference between true and apparent position of a radio star.

spheric reflection point and are heavily weighted by the properties in the vicinity of the reflection level. While the array data from several sources give some information about the horizontal changes in the *F* region, the ionosonde data contain mainly information about the overhead area. For example, the change of phase path with time or Doppler velocity can be measured with the ionosonde and is an estimate of the radial component of the motion of an ionospheric disturbance, while the horizontal component of such a motion should be obtainable from time-lagged correlations of similar features of the array data. Periodicities seen by one system should be in agreement with data from the other system.

Coordinated operation of the two systems should provide, at the very least, information about the magnitude and the direction of motion of ionospheric modifications and possibly some information about the location of their sources, effective lifetimes, and travel distances at ionospheric heights. This kind of information is essential for short-term updating of ionospheric conditions in time and space.

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